A Residential-Scale Fuel Cell Test Facility

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Introduction

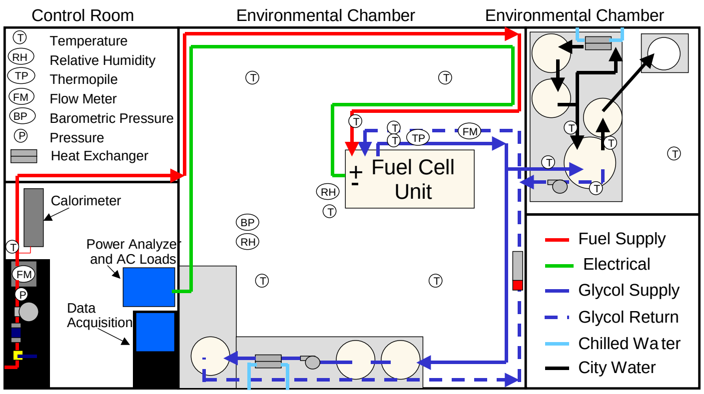

Fig. 1 – NIST's Fuel Cell Test Facility Schematic

A fuel cell laboratory has been established at the National Institute of Standards and Technology (NIST) [1]. The facility is used to develop performance maps and evaluate testing and rating methodologies for stationary fuel cell systems [2, 3]. The laboratory can accommodate units that are fueled by natural gas, propane, or hydrogen. Stationary fuel cell units designed to provide power to the electric utility grid, grid independent units, and fuel cell units that provide thermal as well as electrical power can readily be evaluated within this laboratory. The facility consists of two environmental chambers, a control room, fluid conditioning systems, a programmable electronic load system, and extensive instrumentation, Fig 1. This paper describes the fuel cell laboratory's main components and capabilities.

Environmental Chambers and Control Room

A fuel cell unit under evaluation is placed within a 7 m × 7.6 m environmental chamber. The ambient temperature and relative humidity within this chamber can be controlled over a 0 °C to 40 °C and 20 % to 75 % range, respectively. This environmental chamber also contains one of the two fluid conditioning loops used to evaluate fuel cell units that offer thermal as well as electrical power generation. The chamber's ambient temperature is monitored using radiation shielded type-T thermocouples. The relative humidity within the chamber is determined using three redundant instruments – a dew point hygrometer, a solid state capacitance transducer, and a wet bulb/dry bulb psychrometer.

A smaller environmental chamber (3 m × 3.6 m) provides typical indoor ambient conditions. Any fuel cell equipment specified to be placed indoors is installed within this chamber. Water heaters used to evaluate fuel cell units designed to heat domestic hot water are installed within this chamber. A control room houses a gas meter, gas calorimeter, data acquisition systems, and a personal computer interfaced to the data acquisition systems.

Fig. 2 Gas Calorimeter and Gas Meter

Fig. 3 Fluid Conditioning Loop

Fuel Cell Energy Measurement System

Currently the fuel cell laboratory is configured to test units fueled by natural gas, Fig. 2. A regulator is used to reduce the pressure at the building's natural gas supply to 1.25 kPa. A gas calorimeter provides constant measurements of the fuel's energy content. A dry-type positive displacement natural gas flow meter equipped with proximity sensors, having a resolution of 0.5 L, is used to measure fuel consumption.

The temperature and pressure of the natural gas are measured using a calibrated type-T thermocouple and capacitance type pressure transducer, respectively. These measurements are used to convert the measured gas consumption to standard temperature and pressure conditions (25 °C, 101.3 kPa).

Electrical Energy System

The electrical energy produced by the fuel cell unit can be supplied to the electrical grid or to electrical loads independent of the grid. Digital power analyzers measure the voltage, current, power, and energy delivered. If the fuel cell is operated in the grid independent mode, the electrical energy is dissipated by a programmable electronic load bank. The load bank can be programmed to simulate realistic electrical load profiles.

Fluid Conditioning Systems

The fuel cell laboratory incorporates two independent thermal systems, a fluid conditioning loop and a residential water heating system. The fluid conditioning loop is used to measure a fuel cell's effectiveness in providing thermal energy at various fluid flow rates and temperatures. The flow rate and temperature of the heat transfer fluid entering the fuel cell unit may be varied from .5L/min to 35 L/min and 10 to 55 °C, respectively.

The major components of the fluid conditioning loop include a heat transfer fluid, three 0.3 m^3 (80 gal) storage tanks, a water-to-water heat exchanger, a variable speed centrifugal pump, and a cartridge heater, Fig. 3. The heat transfer fluid consists of a 65 % to 35 %, by volume, mixture of water and propylene glycol, respectively. The heat exchanger dissipates the heat generated by the fuel cell unit to the building's chilled water supply maintained at approximately 7 °C (45 °F). The heat removal rate is controlled by regulating the chilled water supply's flow rate by using a digitally controlled flow valve. The centrifugal pump's speed, chilled-water flow control value, and power supplied to the cartridge heater are controlled by means of PID algorithms incorporated within a *LabView program.

Fig. 4 Residential Water Heating System

Fig. 5 Data Acquisition System and Programmable Electronic Loads

The heat transfer fluid's volumetric flow rate is measured by two independent instruments, a turbine flow meter and a magnetic flow meter. The flow meters were calibrated in-situ at various flow rates and fluid temperatures. Two independent measurements systems are used to measure the temperature of the fluid as it enters and exits the fuel cell unit. The primary system consists of a set of precision platinum resistance thermometers (PRT) and an associated signal conditioning unit. Industrial grade PRTs are used as a secondary means of measuring the fluid temperatures.

In lieu of using the fluid conditioning loop, the fuel cell laboratory's residential water heating system allows a fuel cell unit that includes co-generation to be connected to a simulated use domestic hot water system. The heat transfer fluid passing through the fuel cell unit is passed through an internal heat exchanger within a 0.3 m^3 (80 gal) preheat storage tank by means of a variable centrifugal pump, Fig. 4. Potable water enters this tank at a user selected temperature between 8 °C and 40 °C. The inlet water temperature is selected to replicate the potable water supply temperature for various geographic locations in the United States.

During a hot water draw, water flows from the preheat tank to a 0.25 m^3 (50 gal) electric residential water heater. The hot water leaving the residential water heater flows into a weigh tank positioned on a precision load cell. The hot water draw schedule and duration of each draw are controlled by continuously monitoring the load cell during hot water removals until the target weight is reached. Upon reaching the target weight, the weigh tank is emptied and the tare weight recorded. Unlike the fluid conditioning loop which supplies a constant inlet fluid temperature to the fuel cell, the residential water heating system subjects the fuel cell unit to an inlet temperature that varies considerably. The fluid conditioning loop can dissipate the total thermal energy generated by the fuel cell unit whereas the residential water heating loop limits the thermal energy that be dissipated to the imposed hot water load and thermal losses from the storage tanks.

The temperature of the heat transfer fluid entering and leaving the heat exchanger as well as the potable water temperature as it enters and exits the preheat and residential water heater storage tanks during hot water draws is measured using calibrated Type-T thermocouples. Any electrical energy consumed by the heating elements within the residential water hater in meeting the prescribed load is measured using a calibrated watt transducer.

Data Acquisition System

The output signals from the sensors throughout the laboratory are measured using three 60-channel data acquisition systems. All thermocouple sensors are connected to an isothermal reference temperature block. The initial temperature of the reference block is measured using a precision platinum resistance. The pulse outputs of the gas meter and flow meters are counted by counter cards within the data acquisition systems. Variable output voltage signals and contact closures are provided by cards within the data acquisition system. The gas calorimeter and PRT signal conditioning unit are interfaced directly with the personal computer. A custom written data acquisition and control program written in LabView is used to acquire all experimental data and control the various devices within the laboratory. Figure 5 shows the data acquisition systems, digital power analyzers, and electronic load banks.

Safety System

A normally closed combustible gas solenoid value is installed in the natural gas line serving the laboratory. The solenoid valve terminates the supply of fuel if electrical power to the laboratory is interrupted, an emergency stop button is activated, the measurement and control software is not operational, or the gas detection system with the environmental chambers senses an abnormal condition. The gas detection system monitors the concentration of combustible gases, carbon monoxide, and oxygen within the environmental chambers. The gas detection system closes the fuel solenoid value if the concentration of natural gases reaches 20 percent of the lower explosive limit of hydrogen or if carbon monoxide exceeds 150 ppm. If the concentrations continue to rise an exhaust system is used to replenish the chambers with clean air. If neither of the two actions are sufficient, visible and audible alarms are activated. Finally a separate combustible gas alarm is located adjacent to the gas calorimeter in the control room.

Summary

A residential fuel cell test facility has been constructed at the National Institute of Standards and Technology. The facility is configured to test grid connected and grid independent systems. Fuel cells that provide useful thermal as well as electrical energy can be evaluated using two different thermal systems. One thermal system mimics a residential hot water system subjecting the fuel cell unit to a variable thermal load. The second thermal system is used to improve a constant thermal load at a user selected flow rate and fluid temperature.

The facility will be used to acquire data needed for the development of performance maps, and validation of computer simulation models as well as provide a test bed to evaluate fuel cell testing and rating methodologies.

References

[1] M.W. Davis and A.H. Fanney, “Test Facility for Determining the Seasonal Performance of Residential Fuel Cell Systems,” Proceeding of the Hydrogen and Fuel Cells 2003 Conference and Trade Show, Vancouver, BC, Canada, 9-13 Jun. 2003

[2] M.W. Davis, “Proposed Testing Methodology and Laboratory Facilities for Evaluating Residential Fuel Cell Systems,” NISTIR 6848, Jan. 2002

[3] PTC 50 - 2002 Fuel Cell Power Systems Performance, ASME, 2002

*Certain trade names and company products are mentioned in the test or identified in an illustration in order to adequately specify the experimental procedure and equipment used. In no case does such an identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products are necessarily the best available for the purpose.